Unified Gas and Electricity Distribution Grid Control

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Abstract **- The ongoing development of electricity grids towards smart grids is methodological transferred and described for gas grids. Particularly expected advantages by coupling electricity and gas distribution levels are discussed. One possible result of the coupling is a reduced power grid expansion, which is driven by the ongoing integration of renewable energies. Possible cutback are presumed mainly on the distribution level but also at the transport level. New potential marketing opportunities for facilities and infrastructures arise especially at the gas side. Furthermore, suitable automation approaches for a unified distribution grid control are presented.**

I. INTRODUCTION

The integration of renewable energy generation systems at the distribution grid level creates new requirements for electricity and gas distribution grids. On the one hand, the power distribution grids should be able to manage decentralized power feeds. This creates a need for flexibility options, for example, to address critical grid conditions in a timely manner, to use or store excess amounts of energy, and to source electrical energy in accordance with grid or market signals. On the other hand, the gas distribution grids should be able to include renewable gases, such as biogas or even hydrogen out of power to gas plants. For this purpose, suitable measures should be conceived and taken, e.g. to monitor the composition of the gas or to carry out an efficient use of gas grid capacities [1].

Coupling electricity and gas distribution grids provides suitable answers to the needs of the electricity sector. The need for flexibility options is increasing and can be addressed through different coupling elements. Coupling elements are systems for energy conversion between the different energy grids. Power to gas plants (PtGP) e.g. allow the production of hydrogen or methane using excessive electrical energy from renewables. Combined heat and power (CHP) systems generate simultaneously electricity and heat out of gas. In addition, bivalent systems can generate heat from electricity or gas. In this way, e.g. excess electrical energy in the form of gas from Power to Gas plants can be stored in the gas grid. As a result, the costly power grid expansion is avoided or delayed [1].

To integrate and provide flexibility options, power grids are increasingly being equipped with so-called smart grid systems. These intelligent systems monitor the power grids and make decisions to ensure optimal grid operation using available flexibility options. Since the challenges of the gas grids are increasing due to the decentralized feed-in of biogas and additionally of hydrogen and methane from PtGP, the coupling of the electricity and gas distribution grids ultimately leads to an additional demand for measuring and automation technology.

Considering these ongoing processes, the fundamental requirements for coupled grids are not only limited to technological upgrades of the electricity side. Gas distribution grids have to be enhanced by additional measuring and control technology towards intelligent grids (smart grid).

Accepting this need for further enhancements on both sides, the focus of the project GuStaV (Combined Gas and Electricity Grid Automation at the Distribution Grid Level) is to analyze and develop realization prerequisites for coupled gas and electricity distribution grids. The coupling elements are examined with regard to additional necessary automation requirements. The conceptual developments are prepared for implementation and thus to realize the expected cross-grid advantages.

The aim of the project is to design a unified automation system, as well as the matching of the resulting possibilities. Specific requirements and restrictions for the interface between gas and electricity grids are evaluated. In addition, the organizational and technical challenges as well as specific advantages of a common communication infrastructure are developed.

II. Smart-Grid-Systems

In addition to the often cost-intensive, conventional power grid expansion, innovative grid resources as well as consumer incentives are available as additional options for the integration of renewable energies [2]. Conventional electrical distribution grids can be transformed towards smart grids via integration of monitoring systems and different kinds of actuators. These monitoring system measure the grid conditions in real time and enable the operator to detect critical states on the local and superior levels. These data can be used for a spatial allocation of needed flexibilities and their activation. Thus, the operator can make optimal use of the grid capacity and maximize the feed in of renewable energies [3]. However, this does not mean that the complete grid will be equipped with monitoring systems. It is intended to determine the state of the entire grid on the basis of as few data as possible.

The general goals of a smart grid can be summarized under the following points:

- Integration of renewable energies
- Maintaining the high reliability of distribution grids and avoiding negative influences on supply quality
- Improvement of distribution grid operation and service
- Fast fault location and analysis
- Monitoring of the existing infrastructure and investment planning
- Transparent power flow
- Active load balancing and reorganization of the operation processes

From the perspective of a future point of view, in which electricity and gas grids are coupled, the smart grid approach described above is to be supplemented by a few aspects:

- Electricity and gas grids provide each other with capacities for more efficient grid operation
- Use of decentralized controllable power production - ideally from renewable gases - in times of missing PV and wind power production, e.g. during the wintertime
- Decentralized controllable use of electricity in case of overproduction of PV and wind power by PtGP for the production of renewable gases. Alternatives such as power-to-heat (PtH) are not usable, especially in summer, since only very little heat is needed

III. Current Status and Future Challenges

The following section describes the status and challenges for the electricity and gas sectors and their distribution grids.

A. Electricity Sector

The expansion of renewable energies with a volatile feed-in characteristic driven by the energy turnaround has increased considerably in recent years. About 90% of the installed capacity from renewable energies is connected to the distribution grid level. The distribution grid level, which was often planned 40 years ago, is not designed for the high decentralized power generation and is increasingly reaching the limits of its absorption capacity [2].

In view of this, the electricity distribution grids face great challenges. On the one hand, the feed-in of decentralized generators such as photovoltaic systems leads to an increase in the grid voltage, on the other hand, the utilization of resources can assume critical conditions.

However, the transformation process of the energy transition not only has an impact on the electricity grid, but also on the entire market. For example, the importance of the power exchange EPEXSpot is increasing and opening up many new business opportunities to many market participants [4]. The challenge is the design of applications in which operating systems can benefit as much as possible from all marketing opportunities.

Another future challenge is the politically desired and subsidized expansion of electro mobility. To do this, the existing infrastructure must be expanded with regard to a charging infrastructure. This will only be possible through selective grid expansion and intelligent charging management systems [5].

B. Gas Sector

The coupling with the electricity sector mainly drives the future challenges for the gas distribution grids. The current and expected gas-side potentials for load shifting using bivalent-operated systems (heat generation with both electricity and gas) and for receiving PtGP hydrogen or methane must be continuously identified and made available to the electricity sector. Above all, a discontinuous injection of hydrogen leads to challenges in complying with the limit values for the gas quality and in ensuring compliance with the regulations and the correct billing for end-consumers [6].

Furthermore, the expansion of cogeneration leads to a change in the demand structure, both in terms of time and total demand. In addition to the challenges arising from grid coupling and the optimization of renewable gas feeds, advanced information on the current grid condition and flexibility options are needed [6].

From the perspective of the gas sector, the coupling of the grids is a chance to integrate a bigger amount of renewable energy into the gas grids and for its subsequent use in the electricity, heat or mobility sector [7] [6].

Increasing flexibility in grid operation may be necessary to provide the future capacity required to accommodate renewable gases [8].

Due to the currently not existing monitoring and automation, the needed capacities can't be provided and further control and measurement systems have to be installed.

A suitable concept for increasing the capacity is the dynamic pressure mode, whereby the grid buffer is controlled on-demand by controlling the operating pressure level at the pressure regulator station [9]. The same concept can also be used to increase the capacity for the connection of CHP plants and reduce peak gas purchases from the upstream grids, thereby reducing capacity requirements [9].

IV. Requirements for a cross-sectional automation system

The concept of a unified control system describes a two-phase interaction between local distribution grids and further influences/factors (see figure 1).

In a first step the local status of the grid is forecasted in accordance to the sector, regarding predictions as to capacity, feed, weather etc. The flexibility, which can be provided by the respective connective elements within the grid considered, is not taken into account in this process. The forecast of the grid status (FNS) serves the identification of critical states of the grid.

The FNS in a gas grid anticipates selectively relevant parameters such as the maintenance of minimum pressures and the condition of the gas. Forecasts as to capacity and feed can be created with a prospect of up to 48 hours, depending on the grid area. With this forecast, bottlenecks in the capacity of the gas grid can be identified in advance.

Similar to the FNS in a gas grid the FNS in a power grid is based on forecasts as to capacity and feed as well as on statistical data concerning topology and processes. This data is calculated as well as predicted and can be made available with a prospect of up to 72 hours. Depending on the FNS, schedules for the available connective elements can be created subsequently, considering the specific restrictions (with regard to the connective elements). In case a critical situation was detected by the FNS within the locally monitored distribution grids the connective elements are installed as local flexibility and their schedules planned so that a critical situation can be prevented. If the FNS cannot detect a critical state it evaluates how much flexibility is provided by the monitored distribution grid before a critical situation can occur. Within this free flexibility the connective elements or their flexibility can subsequently be made available on the free market, e. g. by way of an aggregator.

The second step is the identification of the grid status (INS), which determines the local state of the grid in “real time”, using as few measured and calculated data as possible, also taking into account the coordination of the connective elements planned in advance. With the INS and its cyclical operation critical situations can be discovered, which may occur through incorrect forecasts in the FNS or through the production of schedules for the connective elements. In a critical situation the INS allots the control system direct access to the connective elements and therefore to resolve the critical situation.

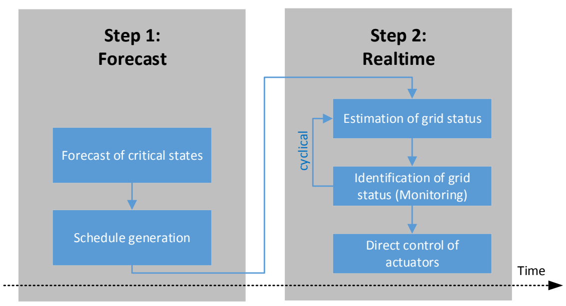

Figure 2 Schematic illustration of a unified control system

Moreover, the control system is able to carry out a priorisation of actuators by way of a sensitivity analysis in case of a critical grid situation. The sensitivity analysis includes economic as well as technical components for identifying the the best possible coordination of the influencing factors in order to defuse specific critical grid situations [9].

Figure 2 shows an exemplary control of a PtGP. In the scenario illustrated the FNS, which monitors the local power grid, predicts a violation of the voltage band caused by an increased photovoltaic feed as well as a subsequent overload of devices due to a linking in of a great capacity. With regard to the violation of the voltage band the sensitivity analysis identifies the PtGP considered as the primary actuator. The reason for this is that the PtGP is installed in a convenient place to resolve the problem and that the costs for activating the PtGP is low due to a bilateral contract between the operator of the distribution grid and the operator of the plant. Moreover, the FNS, which monitors the local gas grid, signals free flexibility regarding the capacity of the gas grid (including pressure, energy value and density). Accordingly, the PtGP is installed as a negative flexibility within the time frame of the predicted violation of the voltage band, i. e. the plant is operating and increases the electrical capacity within the grid and thus avoids a violation of the voltage band. For the resolution of an overload of devices positive flexibility is required within the power grid, i. e. a reduction of the electrical effectivity. However, this cannot be provided by the PtGP as it only represents an additional capacity for the power grid. Yet the PtGP must not be operated during the predicted overload of devices as this would lead to a further increase of the overload. Apart from predicting critical situations PtGPs can provide operating reserves or may be operated according to market signals.

The positive flexibility required may be activated through the control system in various ways. On the one hand, flexible users can reduce their capacity or shut it down completely. Also, decentralised CHP systems as well as batteries can feed the distribution grid and therefore reduce the strain on the respective section of the grid. Furthermore,

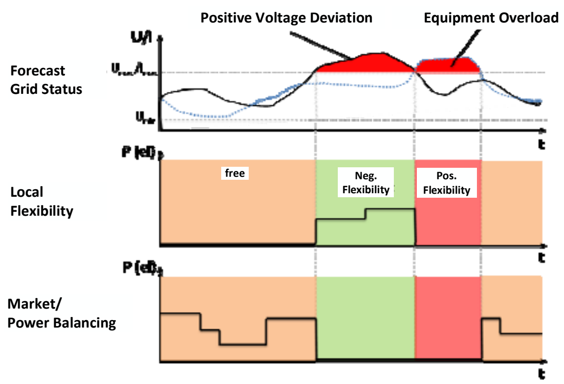

Figure 1 Exemplary control of a PTGP in a critical Situation within the power sector

the installation of CHP systems with required energy reserves makes possible the partial feedback of power of renewable energy hydrogen produced before. Depending on the position of the CHP in the gas distribution grid and the present state of the grid capacity a violation of the pressure band on the part of the gas grid may occur, due to the activation of the positive flexibility for the power grid. The violation of the acceptable pressure level may be compensated for by flexible users, gas storages or a dynamic operation of the pressure in the grid. In a nutshell, this means for gas and power grids that a control system needs to have the opportunity to directly access the actuators or to create incentives for decentralised systems.

A control system does not only bring about benefits for the connective grid operation. Both power and gas distribution grids profit from the opportunities control systems yield for additional measuring and control technology in the grid, e. g. as to the integration of renewable gasses. An example for this is the active usage of a grid buffer, the so-called “dynamic pressure coordination”. Normally, not more renewable gas can be fed into a pressure-regulated distribution grid than is consumed in the same time. In the dynamic pressure-regulated coordination the minimum and maximum pressures of the grid are specifically actived through feed control. During hours with a high demand on gas the withdrawal of gas at the control system is reduced, which leads to a reduction of the pressure in the grid. In the following hours the grid can be buffered up with renewable gasses up to maximum pressure. This leads to an increase in the capacities for the feed of biogas or SNG from PtGPs. In an exemplary model grid (rural medium-pressure grid) the capacities for the reception of renewable gasses could be raised by nearly 40 per cent. This however requires, apart from knowledge or the forecast of the load profile of the gas demand, not only the opportunity for a specific regulation of the feed, but also the monitoring of minimum and maximum pressures in the grid.

V. Summary and Outlook

This paper shows that future co-ordinated interaction between the electricity and gas distribution grids will provide benefits for the previously separate energy distribution grids. It is possible to eliminate bottlenecks in electrical distribution grids by free capacities in the gas distribution grid. In addition, sector coupling will create new marketing opportunities for the coupling elements between electricity and gas distribution grids. Successful and comprehensive sector coupling requires further expansion of measuring and automation technology within distribution grids. In addition, standardized interfaces must be created between the individual actors, such as the distribution system operator, aggregator or the plant operator.

In addition, the presented project provides a basic understanding of the respective control needs in order to reliably fulfill the supply tasks of the electricity and gas distribution grids, even with a distribution grid coupling. Furthermore, it shows that the interaction of the electricity and gas sector can make an important contribution to the success of the transformation process of the German energy supply by means of suitable automation.

The next steps of the research project are on the one hand the time-resolved simulations of the coupling elements under the influence of the higher-level regulatory authorities and on the other deducting technical recommendations for a unified automation system and its effects on official regulations.

VI. Funding Notes

The presented project is being carried out under the leadership of the Chair of Electrical Energy Supply Technology (EVT) of the Bergische Universität Wuppertal together with the DBI-Gastechnologisches Institut gGmbH, GWI - Gas and Wärme-Institut Essen eV and the DVGW Research Center at the Engler-Bunte-Institut. The German Gas and Water Association (German acronym DVGW) funds the project with a term of 24 months.

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